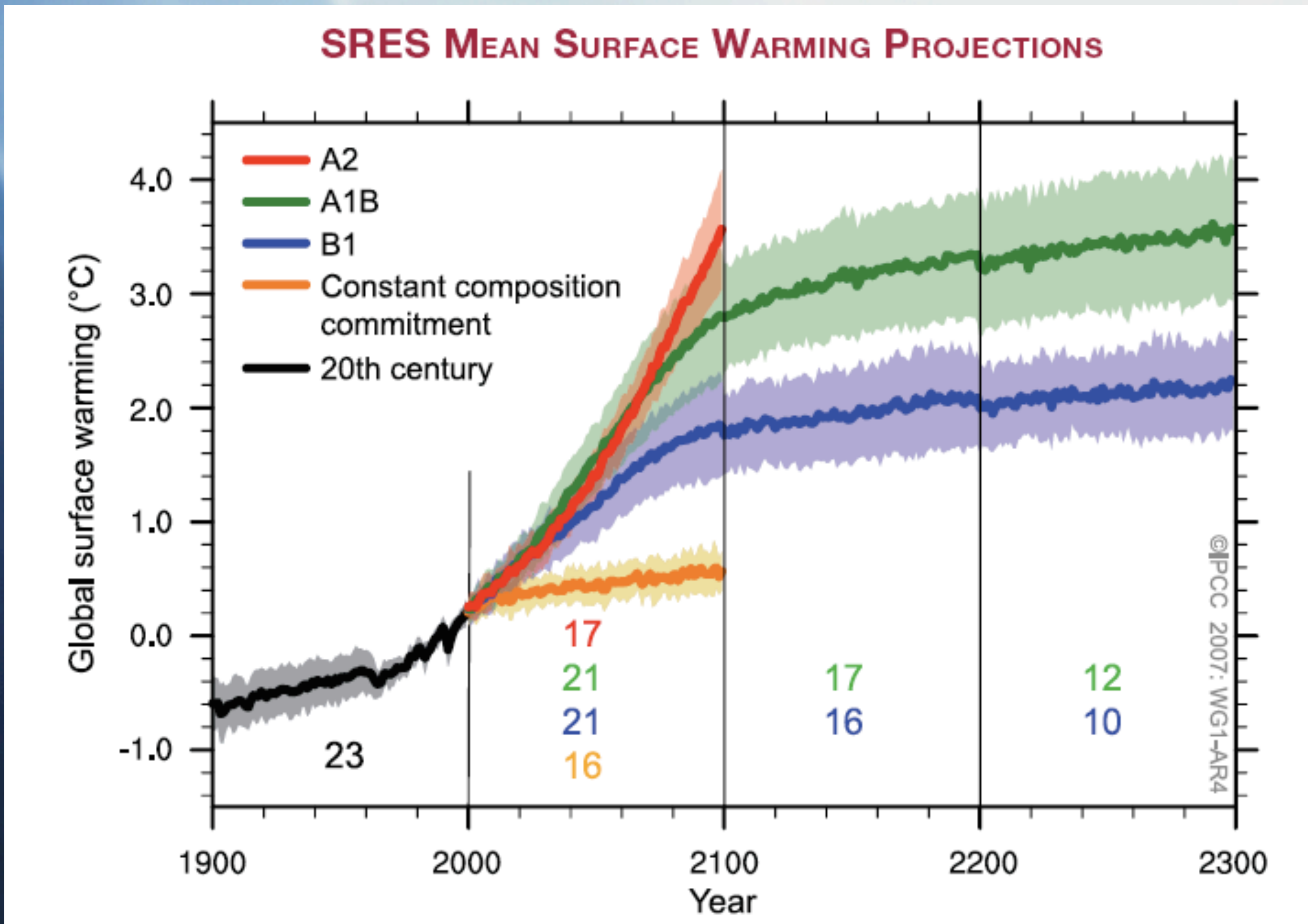
Seasonal Contributions to Climate Feedbacks in the NCAR CCSM3.0

Patrick Taylor

CERES Science Team Meeting

November 4, 2009

Uncertainty in Model Predictions



Climate Sensitivity

- Climate Sensitivity Parameter:

$$\lambda = \frac{\Delta F_{ext}}{\Delta T_s}$$

- Assuming a small perturbation,

$$\Delta F_{ext} \approx \Delta R_T + \Delta R_r + \Delta R_C + \Delta R_\alpha$$

- This is justified considering a first-order Taylor Series expansion of R_2 in terms of R_1.

$$R_2 \approx R_1 + \frac{\partial R_1}{\partial x}\delta x + \frac{\partial R_1}{\partial r}\delta r + \frac{\partial R_1}{\partial T}\delta T + \frac{\partial R_1}{\partial C}\delta C + \frac{\partial R_1}{\partial \alpha}\delta \alpha$$

Climate Sensitivity

- Substituting into climate sensitivity parameter

$$\lambda = \frac{1}{\Delta T_s}(\Delta R_T + \Delta R_r + \Delta R_C + \Delta R_\alpha)$$

- Using the definition of the feedback sensitivity parameter, $\lambda_C = \frac{\Delta R_C}{\Delta T_s}$, we obtain

$$\lambda = \lambda_T + \lambda_r + \lambda_C + \lambda_\alpha$$

- Strictly, radiative perturbations are defined as partial derivatives.

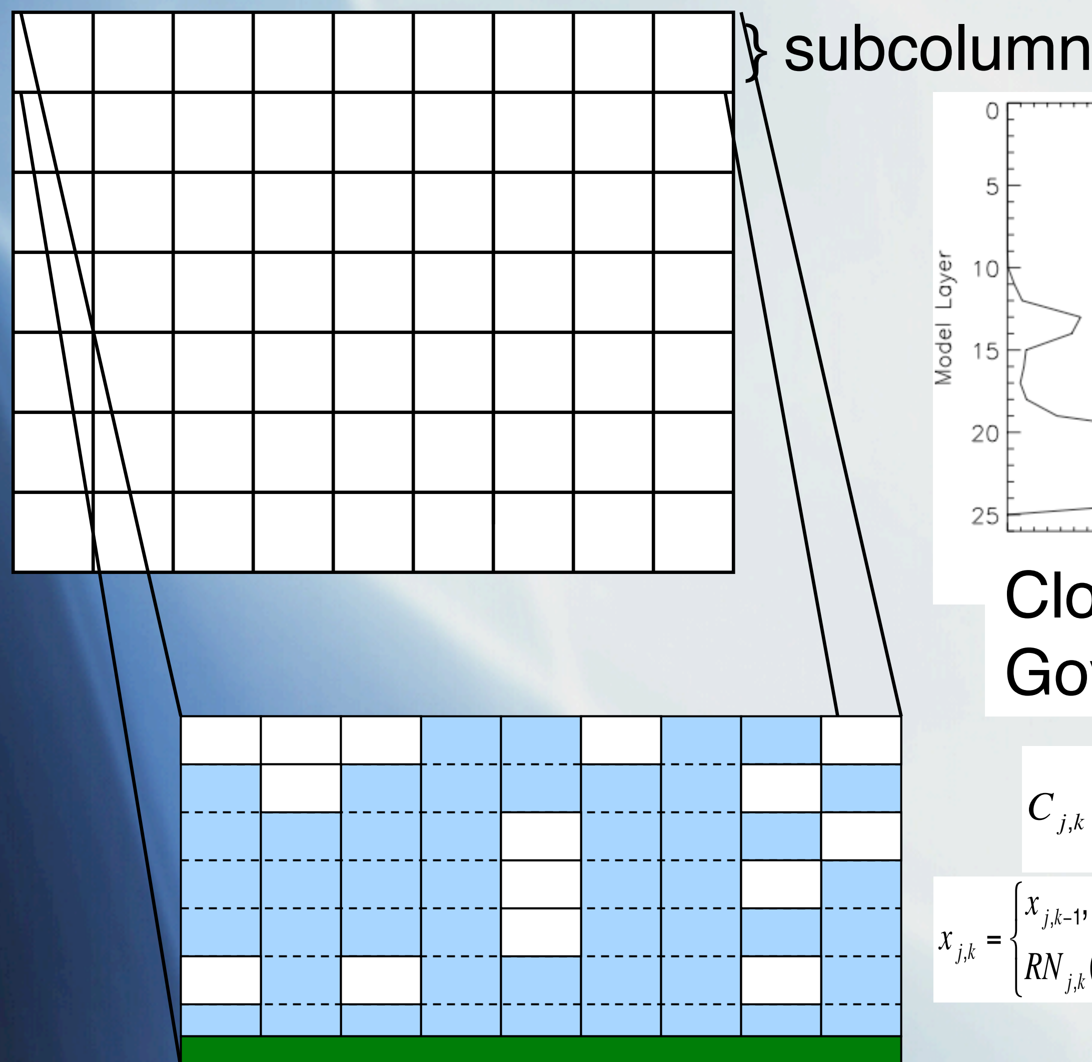
$$\Delta R_C = \frac{\partial R}{\partial C}\delta C$$

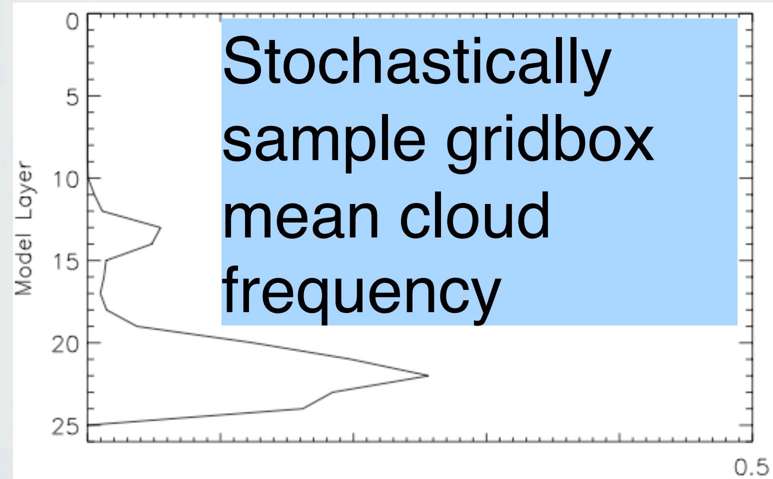
Model Information

- NCAR CCSM3.0
  - T85 resolution- 1.41°x1.41°
  - Coupled Ocean
- SRESA1B IPCC AR4
  - 1% per year increase in CO_2 until 2100.
  - Approximate doubling of CO_2 by 2100.

MCICA Subcolumns

Large-scale model Gridbox





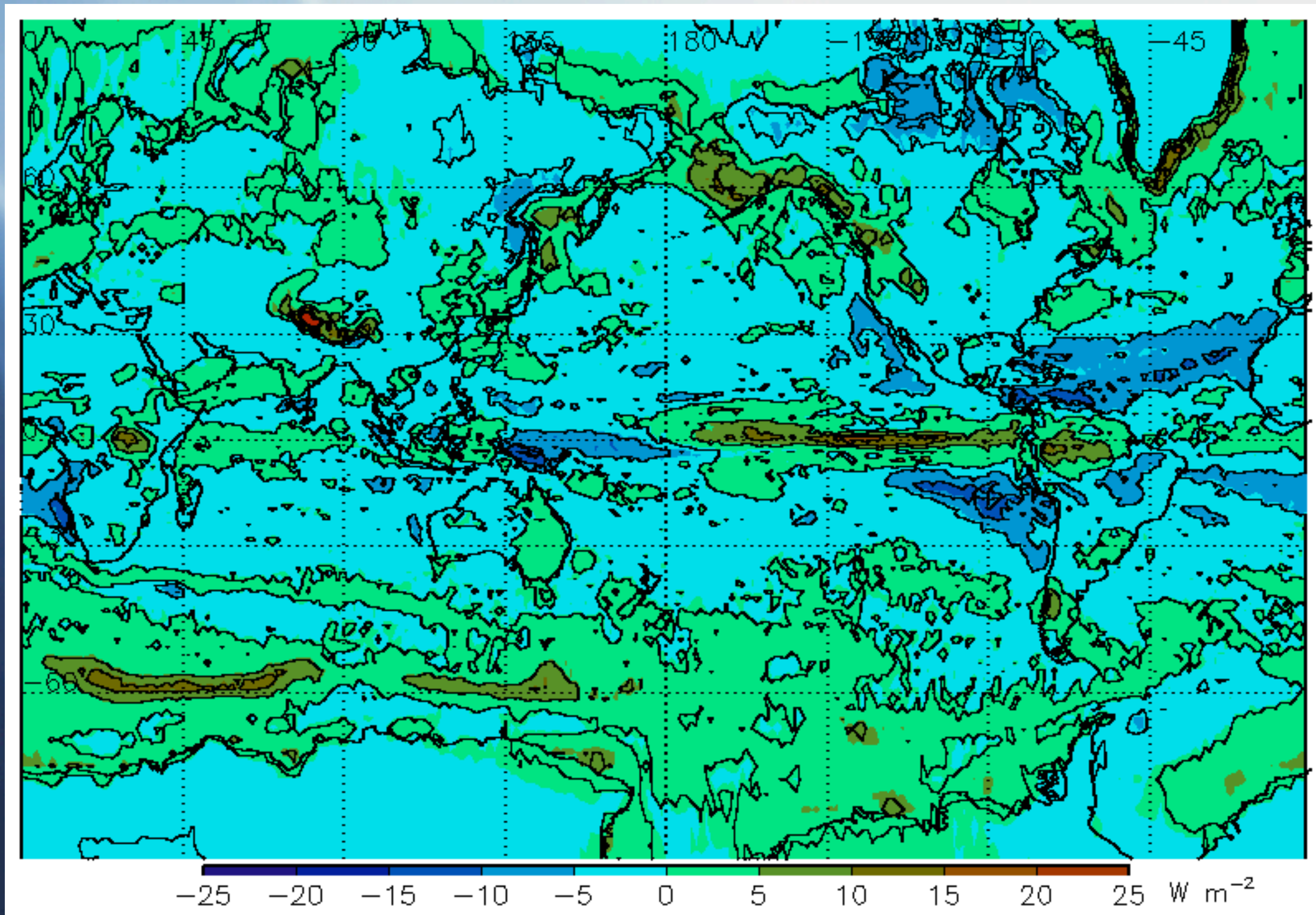
Cloud Generator Governing Equations

$$C_{j,k} = \begin{cases} 0, \ for \ x_{j,k} \le 1 - C_k \ (clear) \\ 1, \ for \ x_{j,k} > 1 - C_k \ (cloudy) \end{cases}$$

$$x_{j,k} = \begin{cases} x_{j,k-1}, \ for \ x_{j,k-1} > 1 - C_{k-1} \ (cloudy\ cell\ above) \\ RN_{j,k}(1 - C_{k-1}), \ for \ x_{j,k-1} \le 1 - C_{k-1} \ (cloudless\ cell\ above) \end{cases}$$

Linearity Test

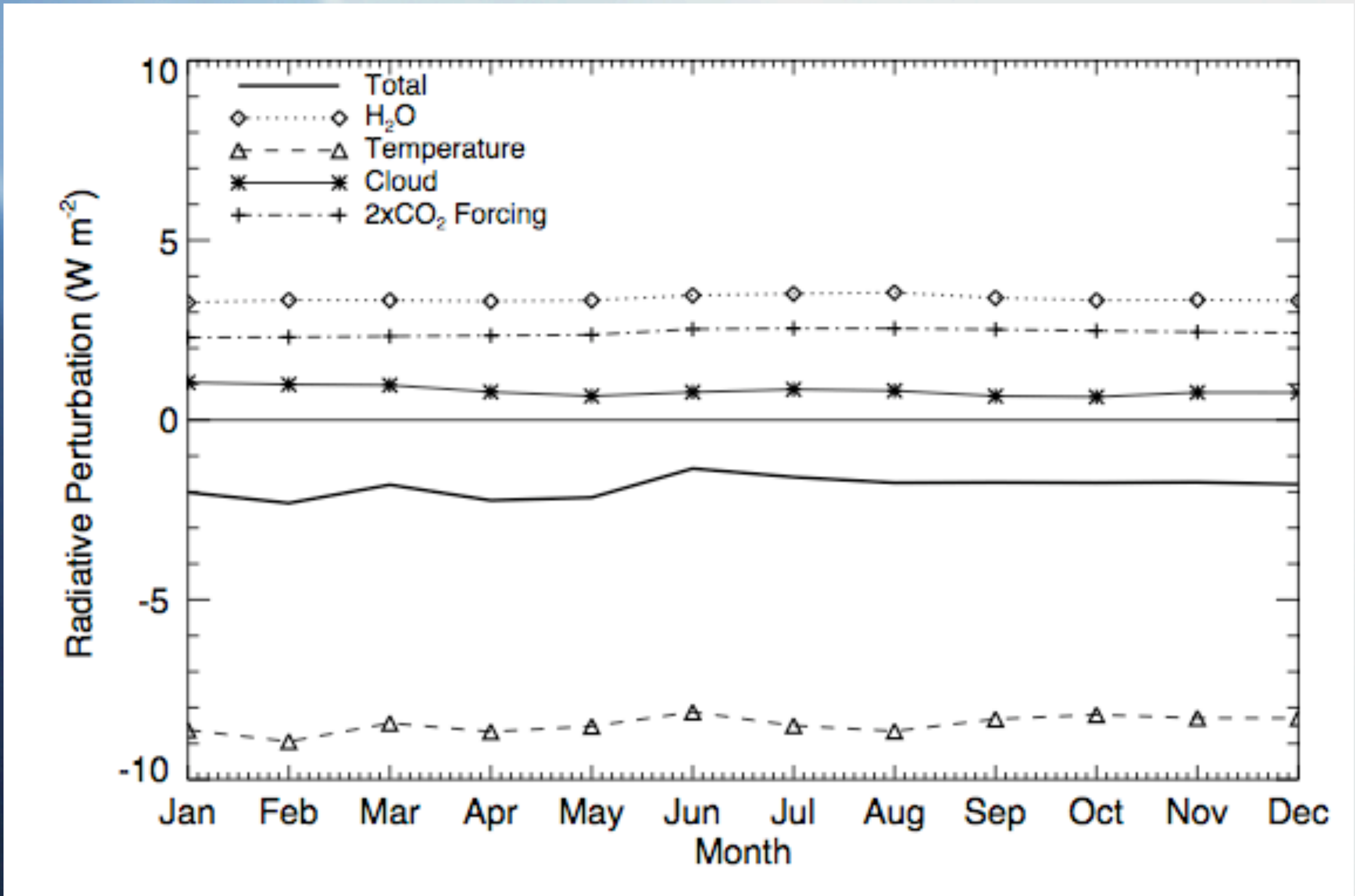
$$R_2 - R_1 \approx \frac{\partial R_1}{\partial x}\delta x + \frac{\partial R_1}{\partial r}\delta r + \frac{\partial R_1}{\partial T}\delta T + \frac{\partial R_1}{\partial C}\delta C + \frac{\partial R_1}{\partial \alpha}\delta \alpha$$



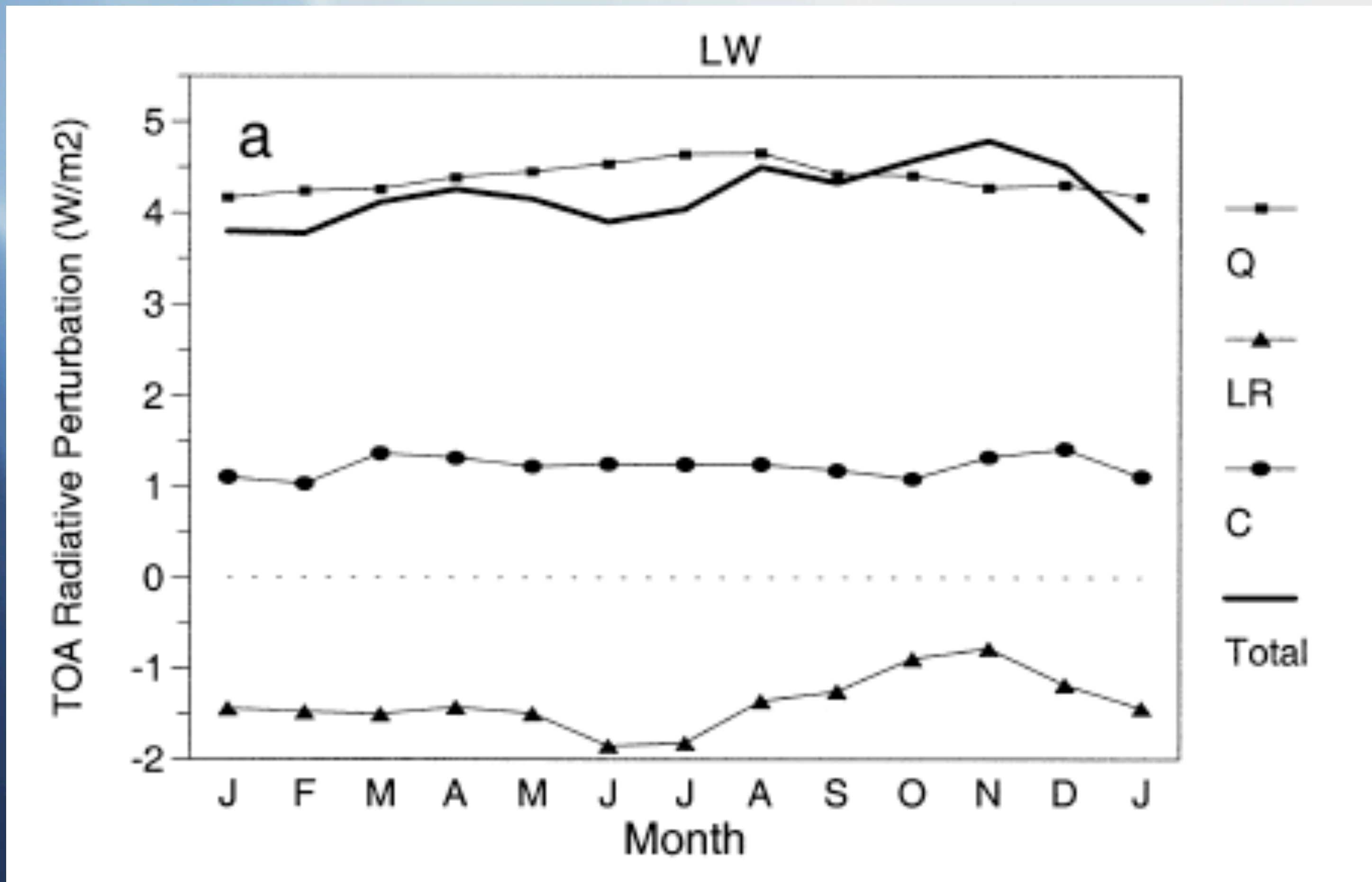
Results: TOA Radiative Forcing and Perturbations

Seasonal Cycle

Global Mean: Longwave

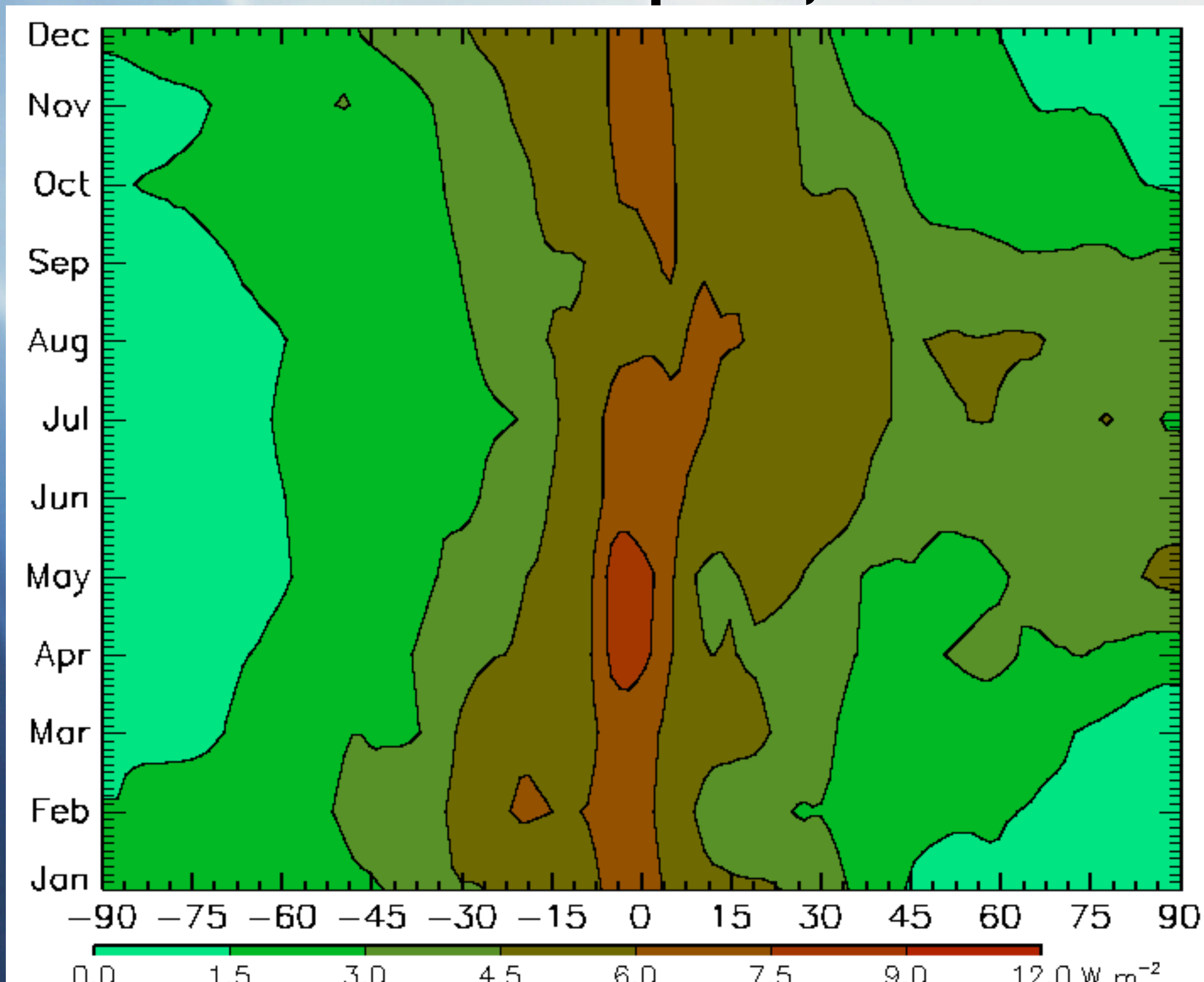


CCSM3.0 vs. BMRC

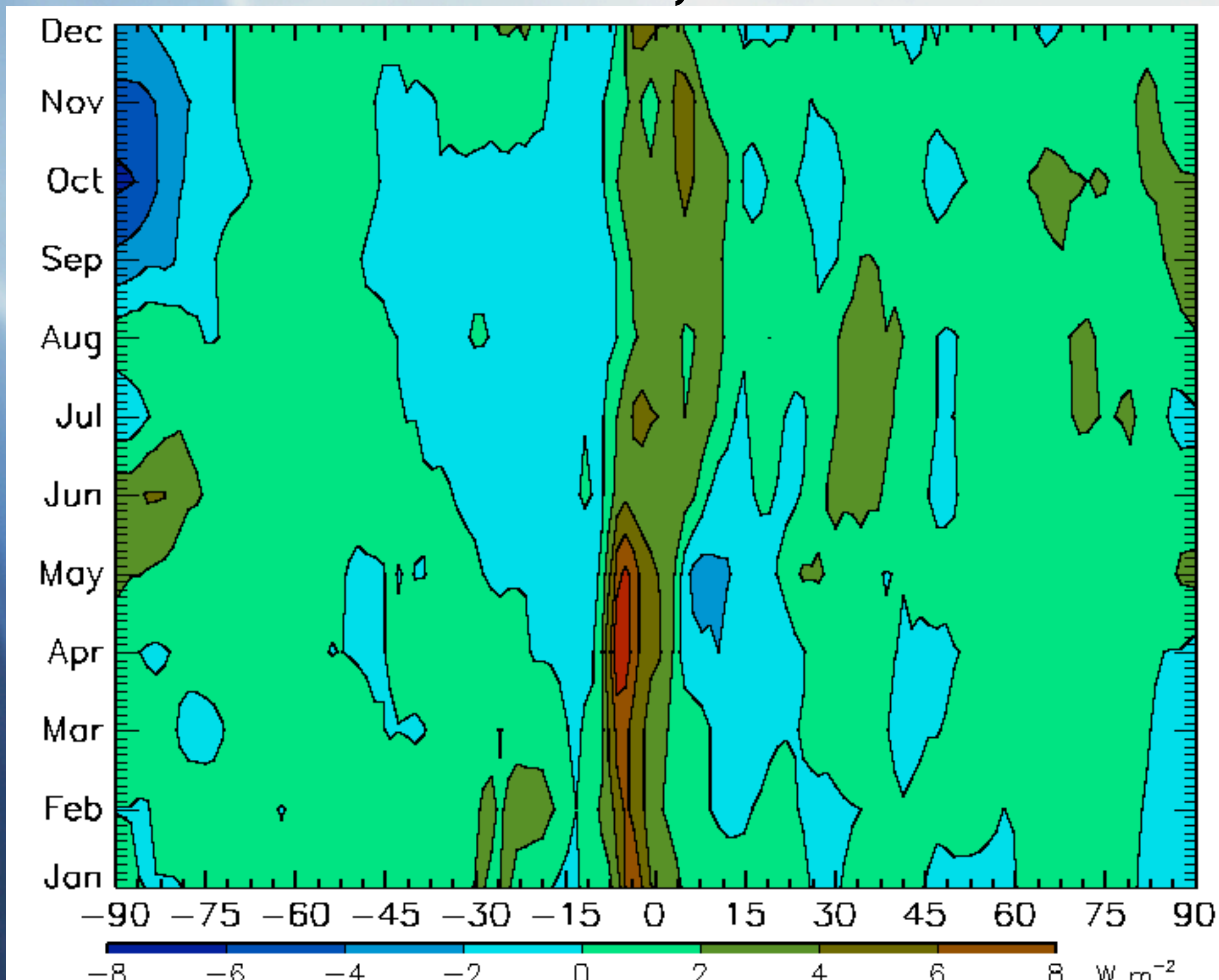


Colman (2003)

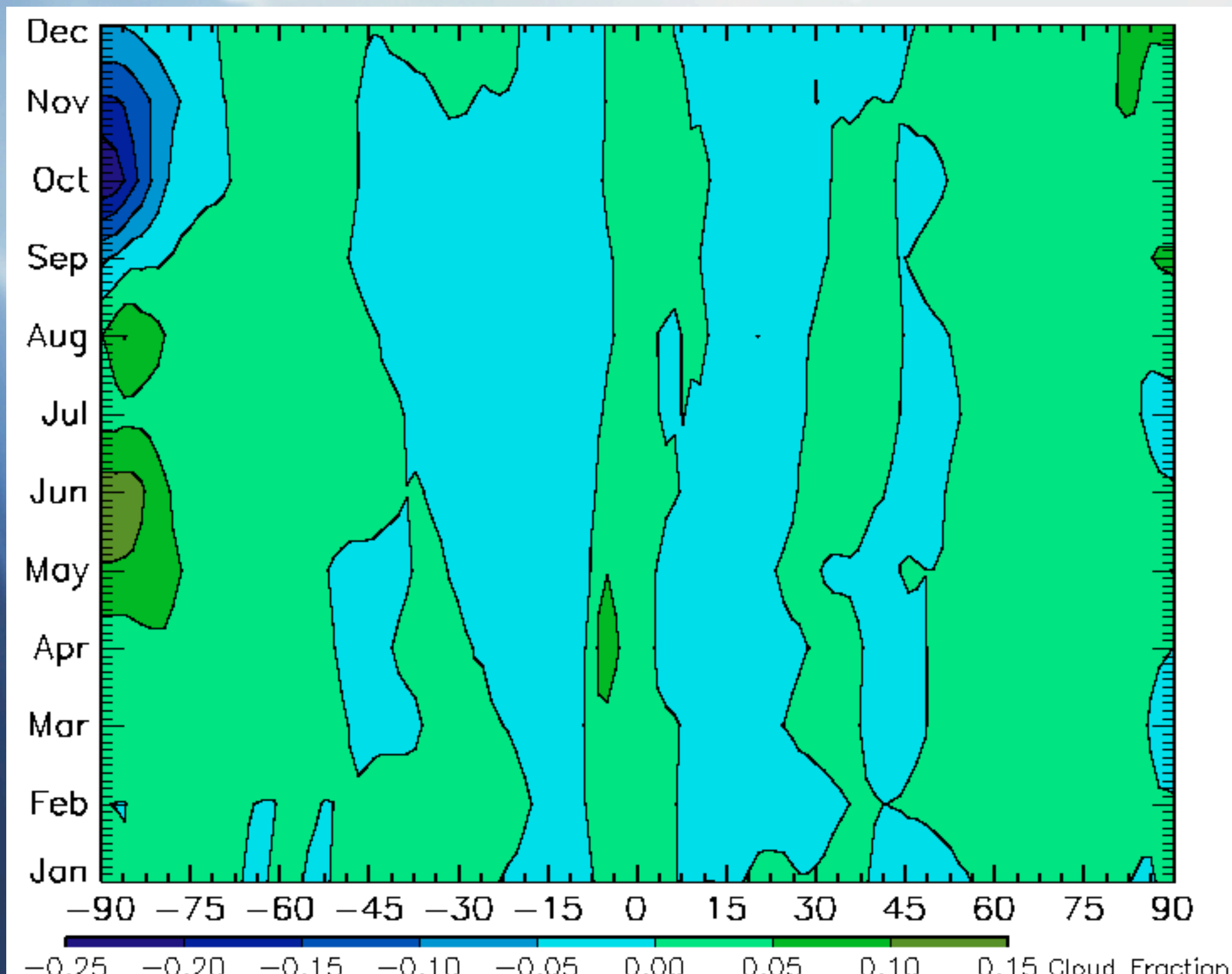
Seasonal Variations: Water Vapor, LW



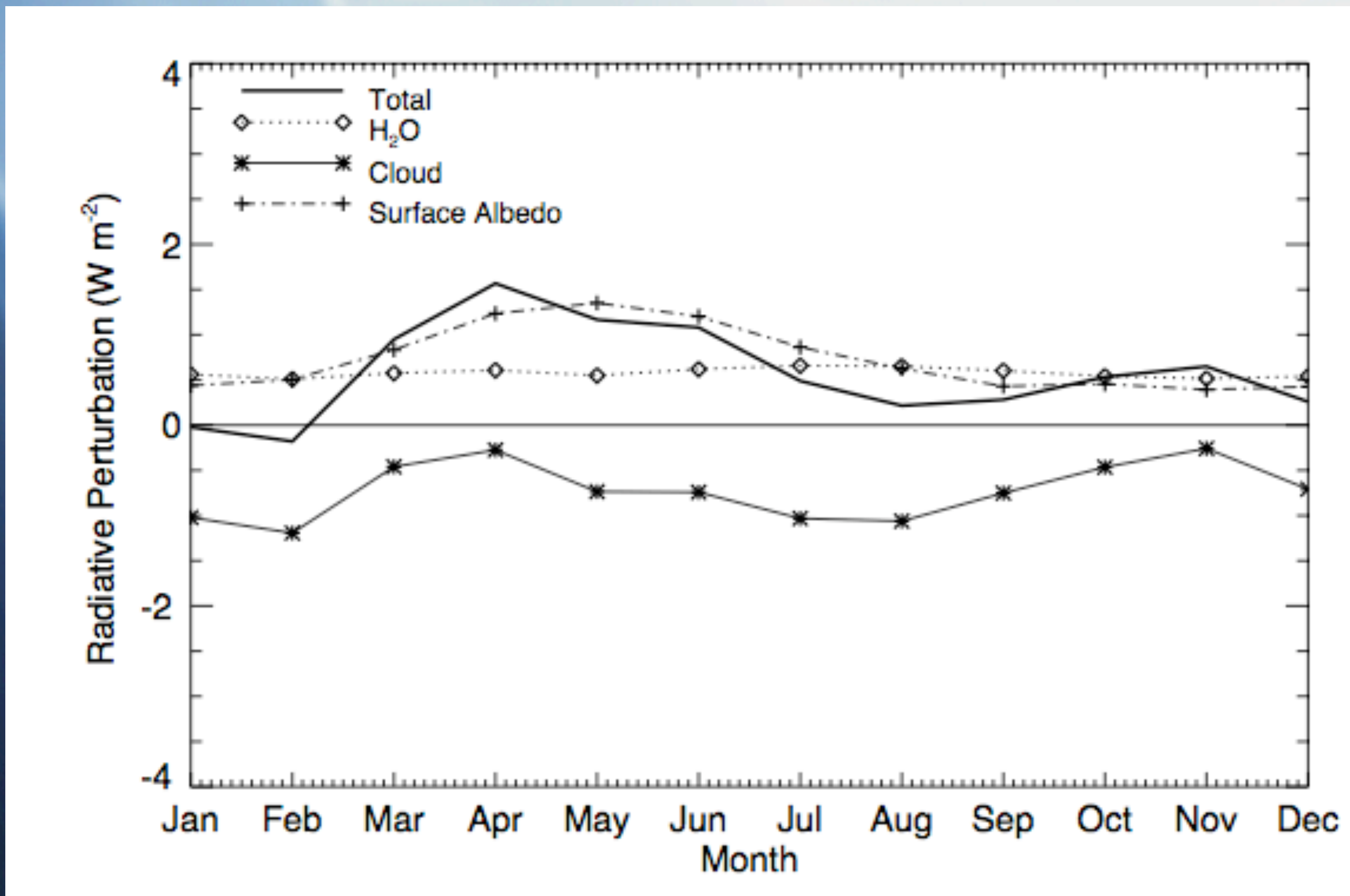
Seasonal Variations: Clouds, LW



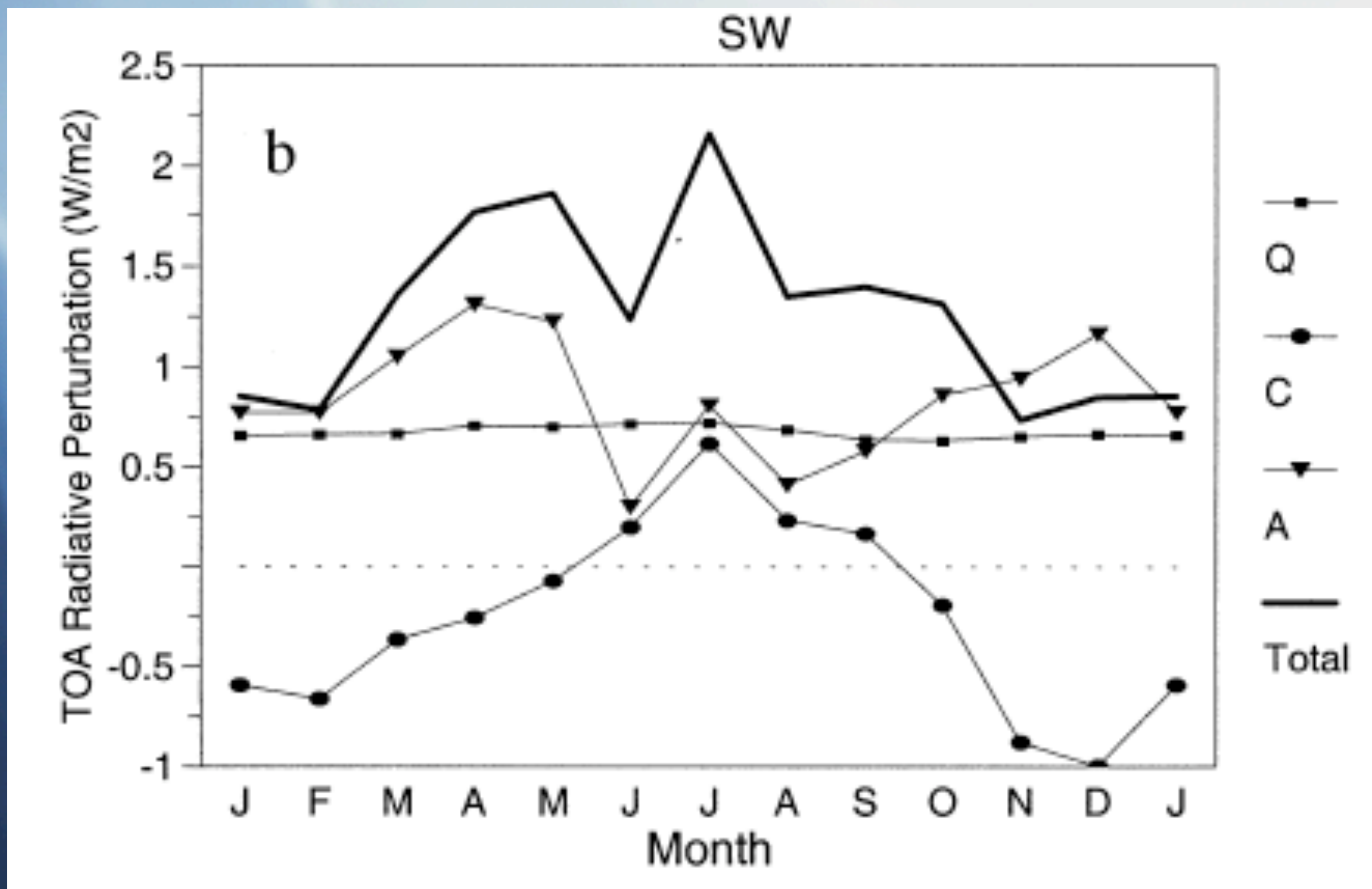
Seasonal Variations: High Cloud Response



Global Mean: Shortwave

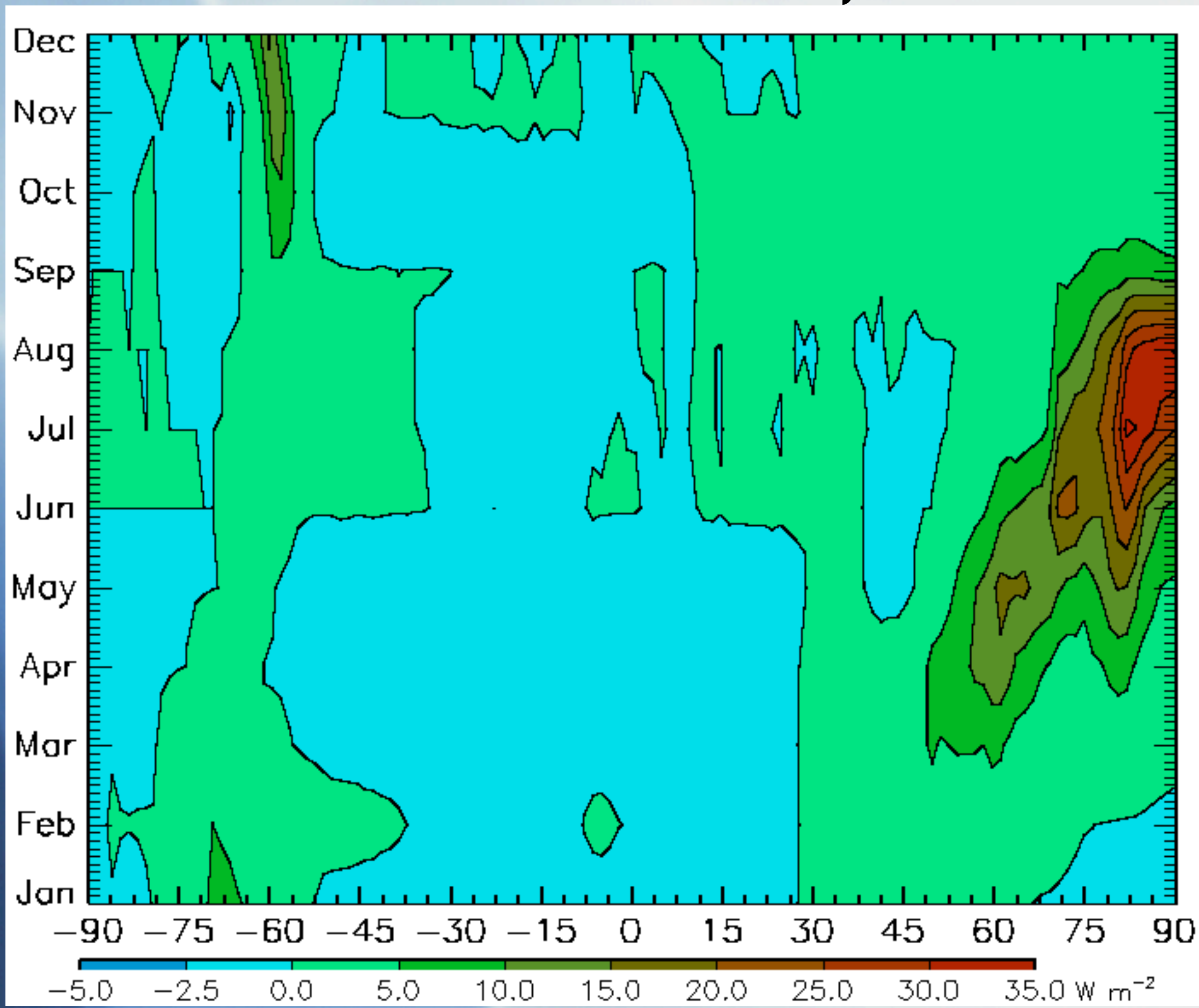


CCSM3.0 vs. BMRC

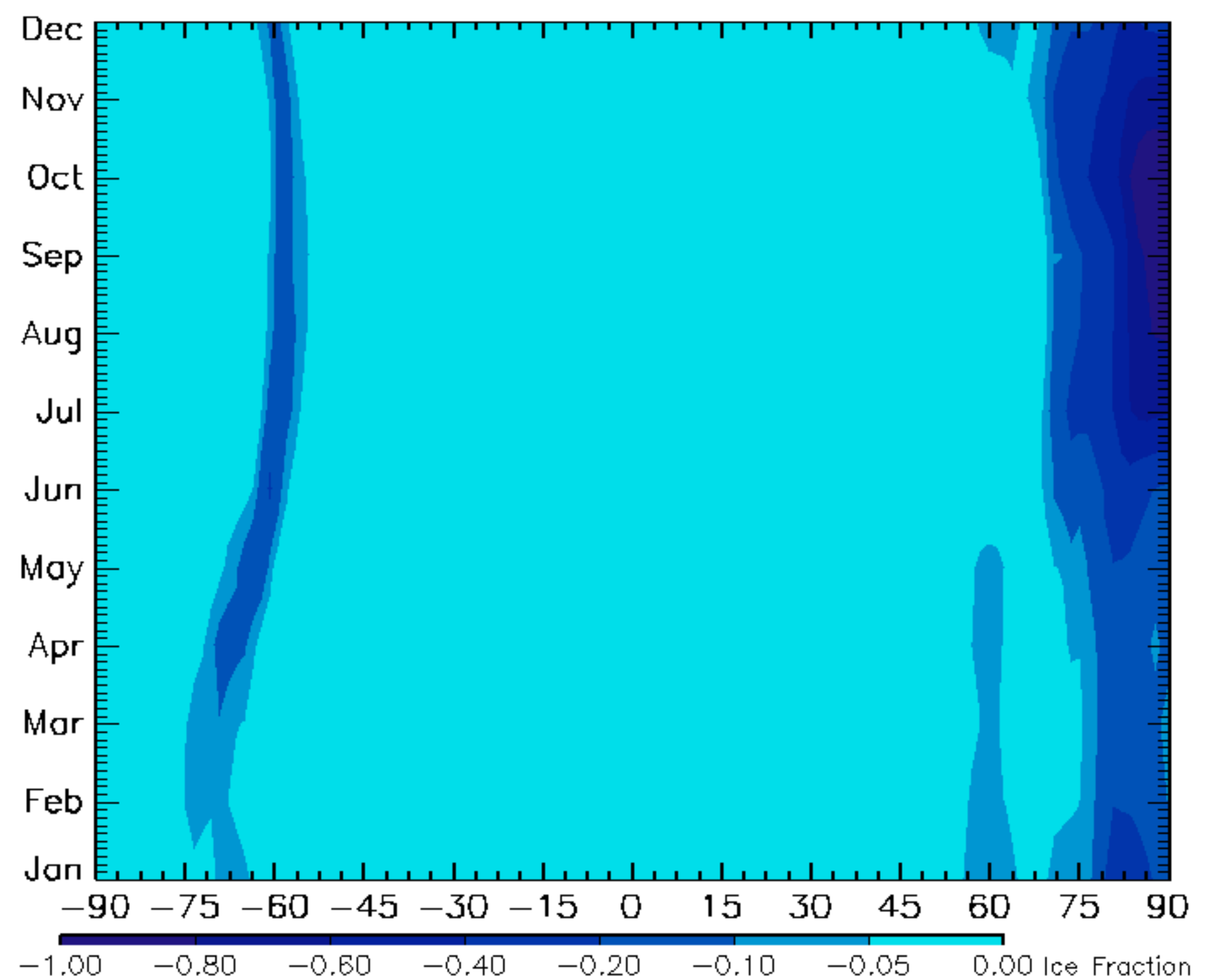


Colman (2003)

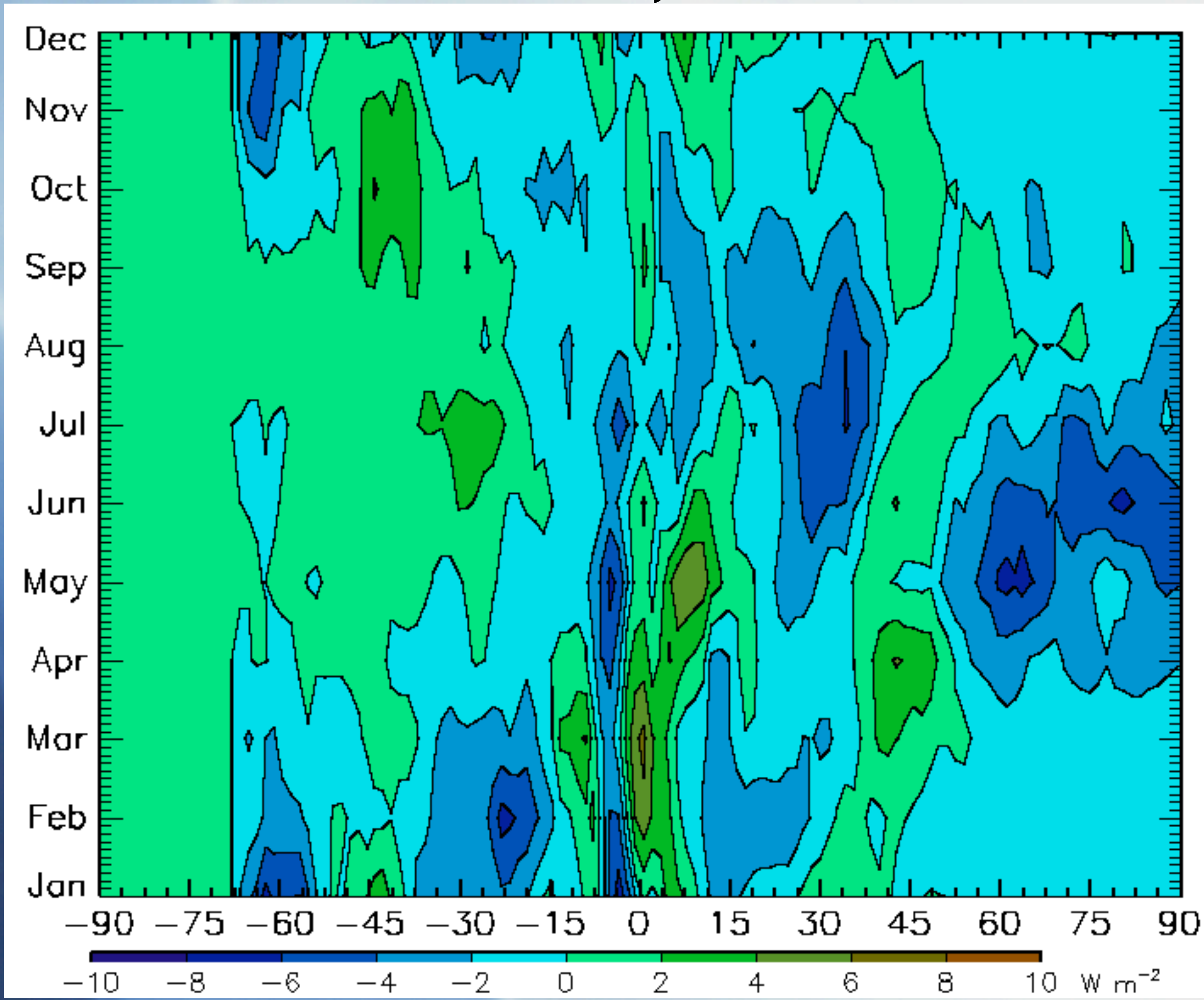
Seasonal Variations: Surface Albedo, SW



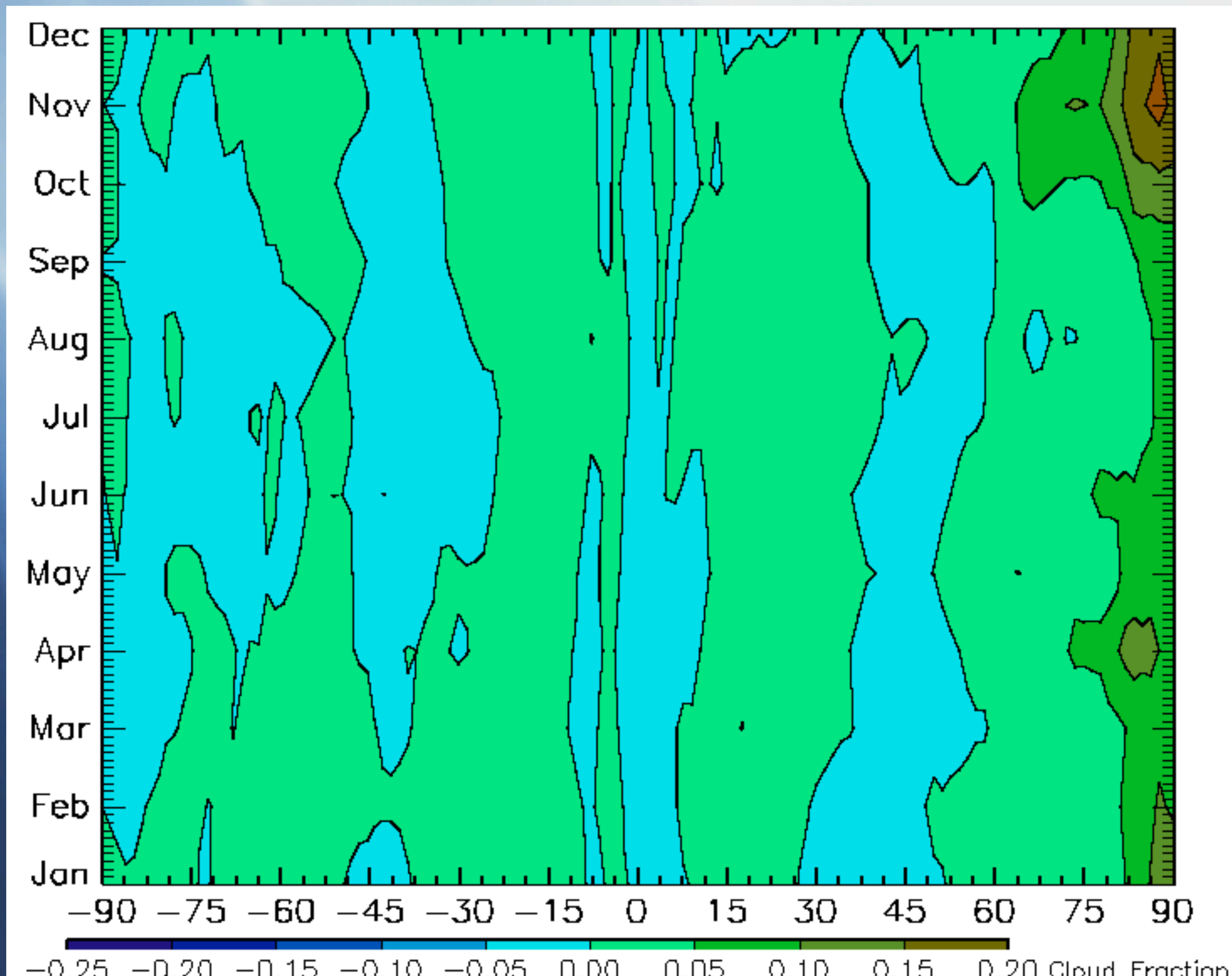
Seasonal Variations: Ice Response



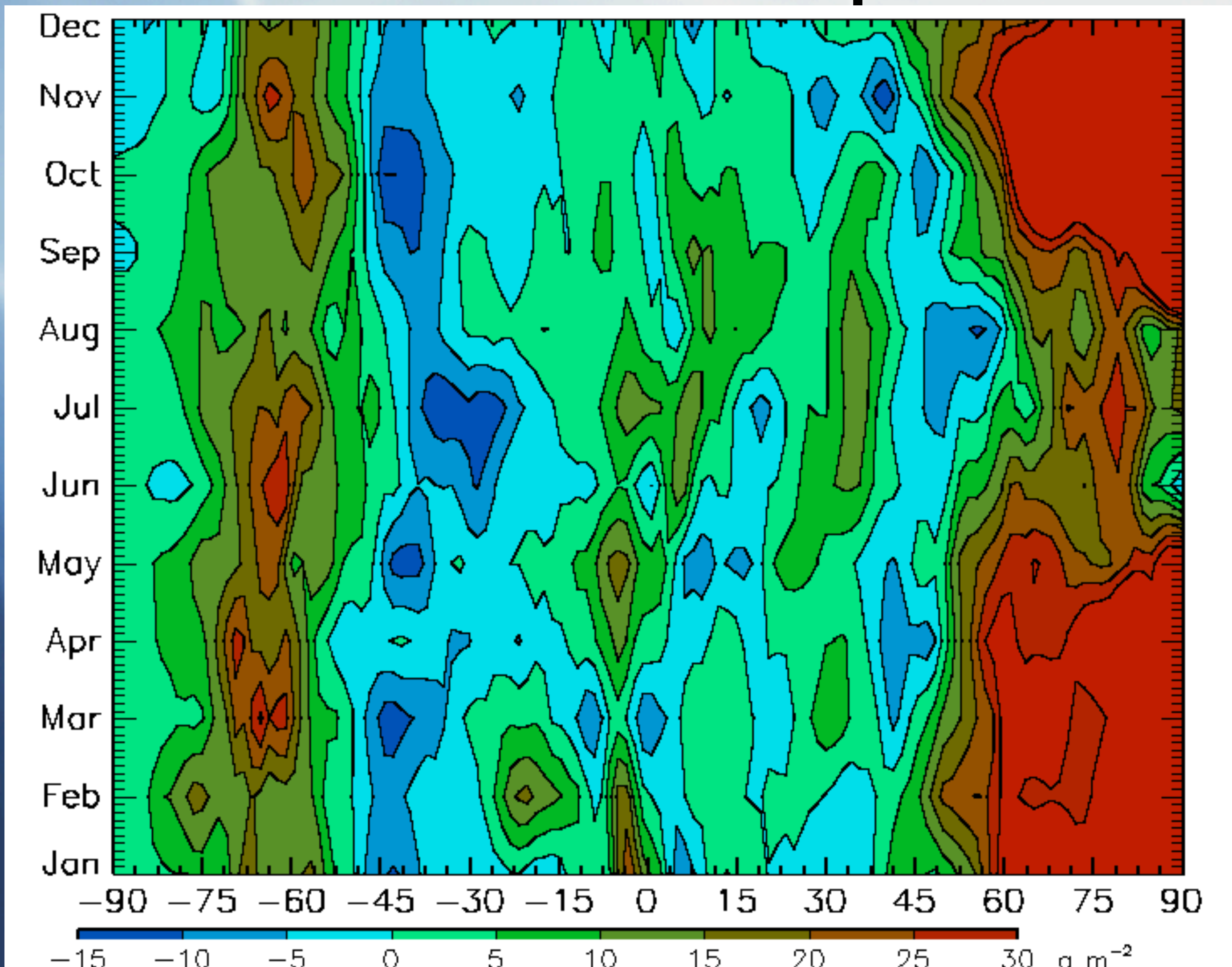
Seasonal Variations: Clouds, SW



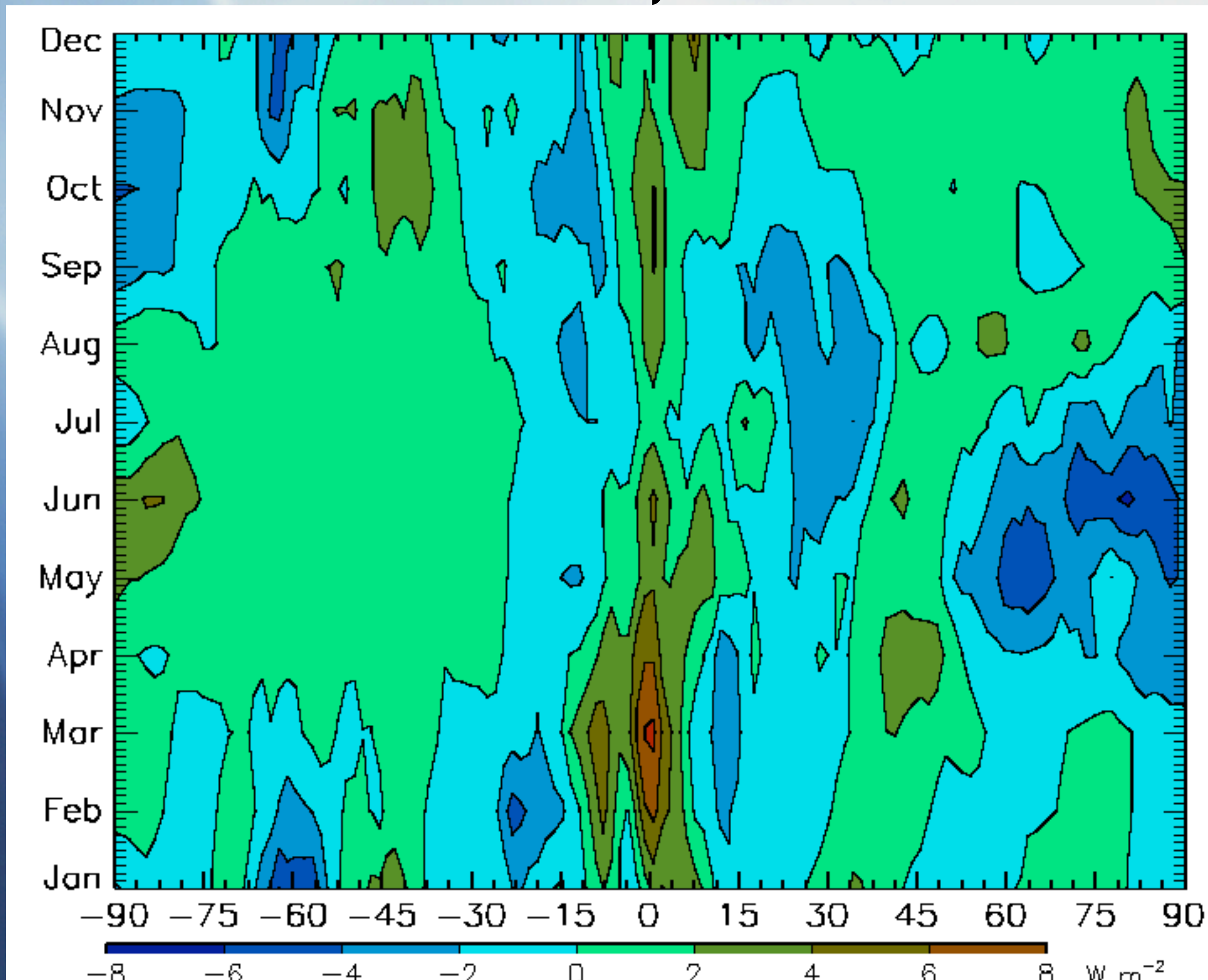
Seasonal Variations: Low Cloud Response



Seasonal Variations: Cloud LWP Response



Seasonal Variations: Clouds, Net



Summary and Conclusions: Seasonal Variability

- The global-mean seasonal contributions to the LW feedbacks show no seasonal variability.
- Differences are exhibited between the global-mean seasonal contributions to the SW feedbacks in the NCAR CCSM3.0 and the results of Colman (2003).
  - Small differences in surface albedo
  - Large differences in cloud feedback
- The pattern of the zonal mean contributions between the the CCSM3.0 and Colman (2003) are small, however large inter-model differences in radiative perturbation magnitudes were found.

Selected References

Colman, R., 2003: Seasonal contributions to climate feedbacks. *Climate Dyn.,* **20**, 825-841.

Pincus, R., H. W. Barker, and J.-J. Morcette, 2003: A fast, flexible, approximate technique for computing radiative transfer in inhomogeneous cloud fields. *J. Geophys. Res.*, **108**, 4376, doi: 10.1029/2002JD003322.

Raisanen, P., H. W. Barker, M. F. Khairoutdinov, J. Li, and D. A. Randall, 2004: Stochastic generation of subgrid-scale cloudy columns for large-scale models. *Quart. J. Roy. Meteor. Soc.* **130,** 2047-2067.

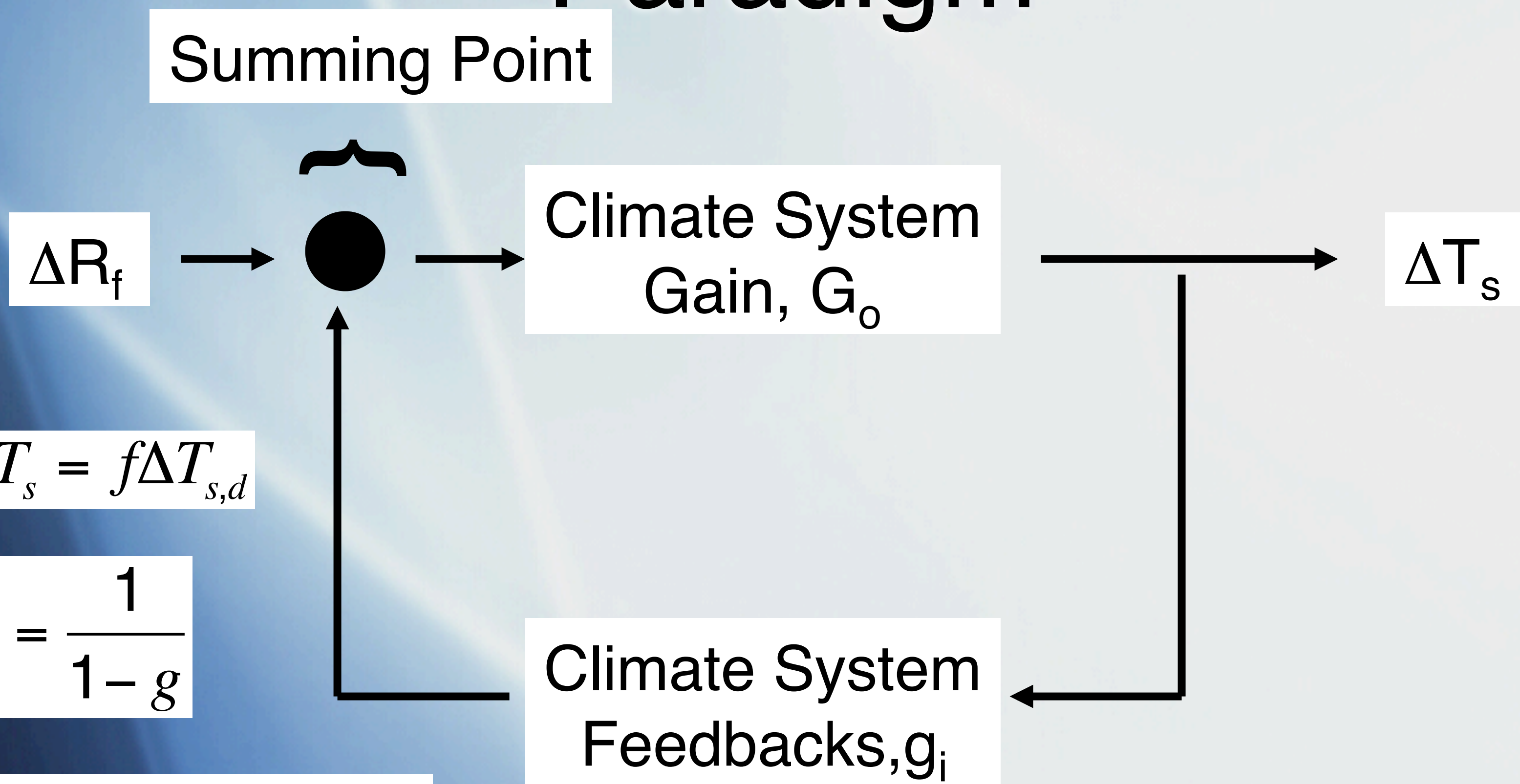
Randall, D. A. and coauthors, 2007: Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Soden, B. J. and I. M. Held, 2006: An assessment of climate feedback in coupled ocean-atmosphere models. *J. Climate*. **19,** 3354-3360.

Solomon, S. and coauthors, 2007: Technical Summary. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Wetherald, R. T., and S. Manabe, 1988: Cloud feedback processes in a general circulation model. *J. Atmos. Sci.*, **45,** 1397-1415.

Forcing-Response-Feedback Paradigm



$$\Delta T_s = f \Delta T_{s,d}$$

$$f = \frac{1}{1-g}$$

$$g = \sum_i g_i = \sum_l \frac{\lambda_i}{-\lambda_P}$$

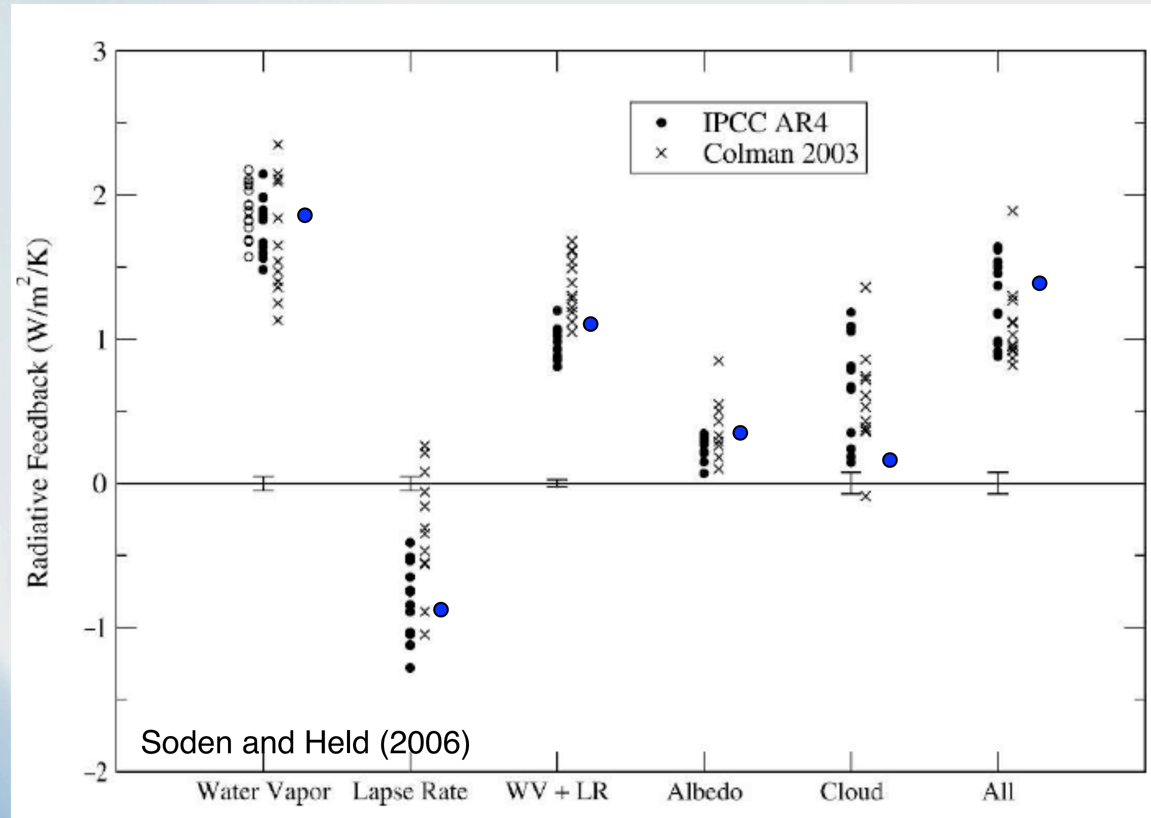
Feedback Uncertainties

λ_W=+1.80 ±0.18 $Wm^{-2}K^{-1}$

λ_Γ=-0.84 ±0.26 $Wm^{-2}K^{-1}$

λ_α=+0.26 ±0.08 $Wm^{-2}K^{-1}$

λ_C=+0.69 ±0.38 $Wm^{-2}K^{-1}$



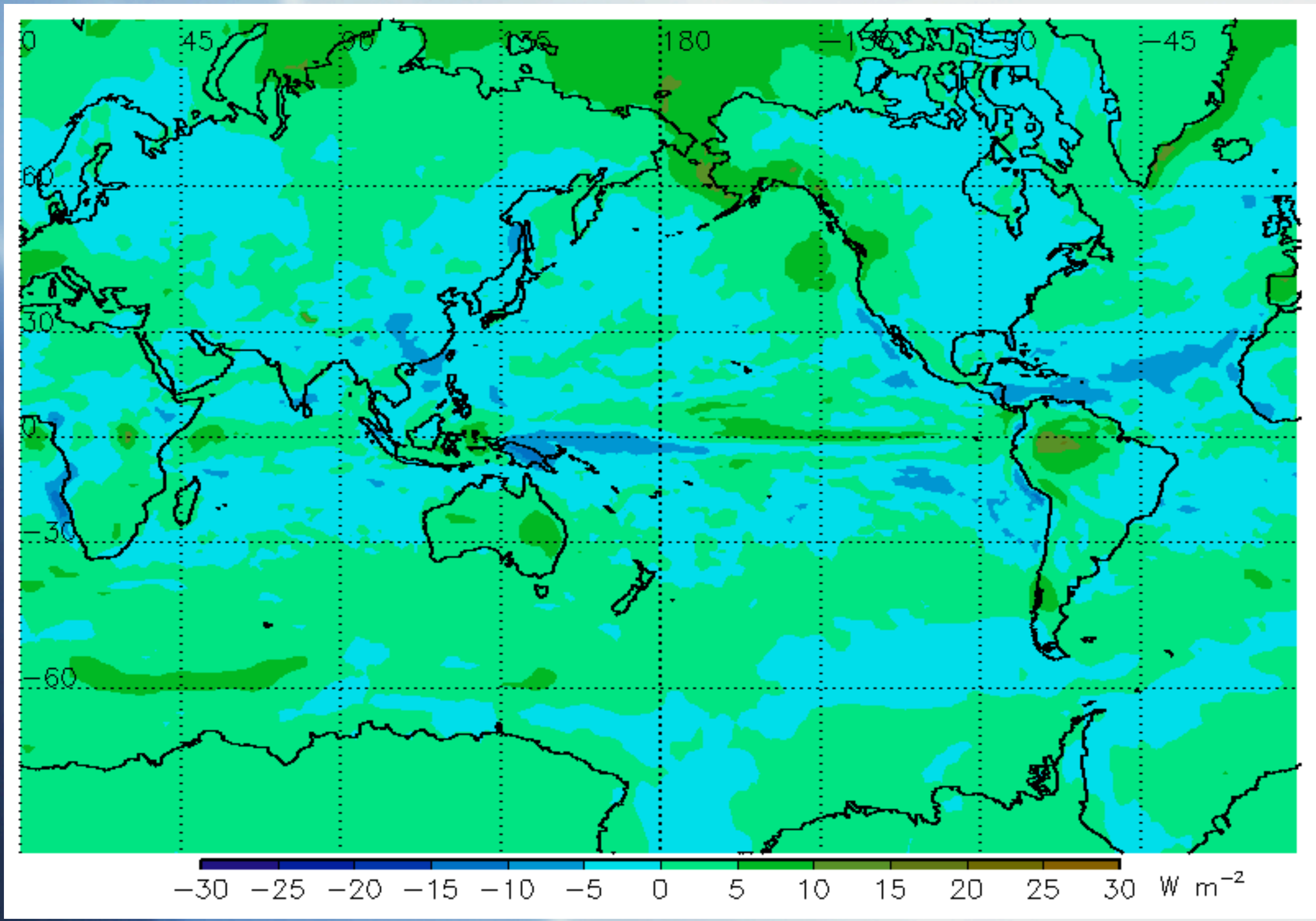
Feedback Sensitivity Parameter

- Feedback Sensitivity Parameter: $\lambda_C = \frac{\Delta R_C}{\Delta T_s}$
- TOA Radiative Perturbation: $\Delta R_C = \frac{\partial R}{\partial C}\delta C$
- Calculation of TOA Radiative Perturbation (Wetherald and Manabe 1988): $\Delta R_C = R(x_1, T_1, r_1, C_2, \alpha_1) - R(x_1, T_1, r_1, C_1, \alpha_1)$

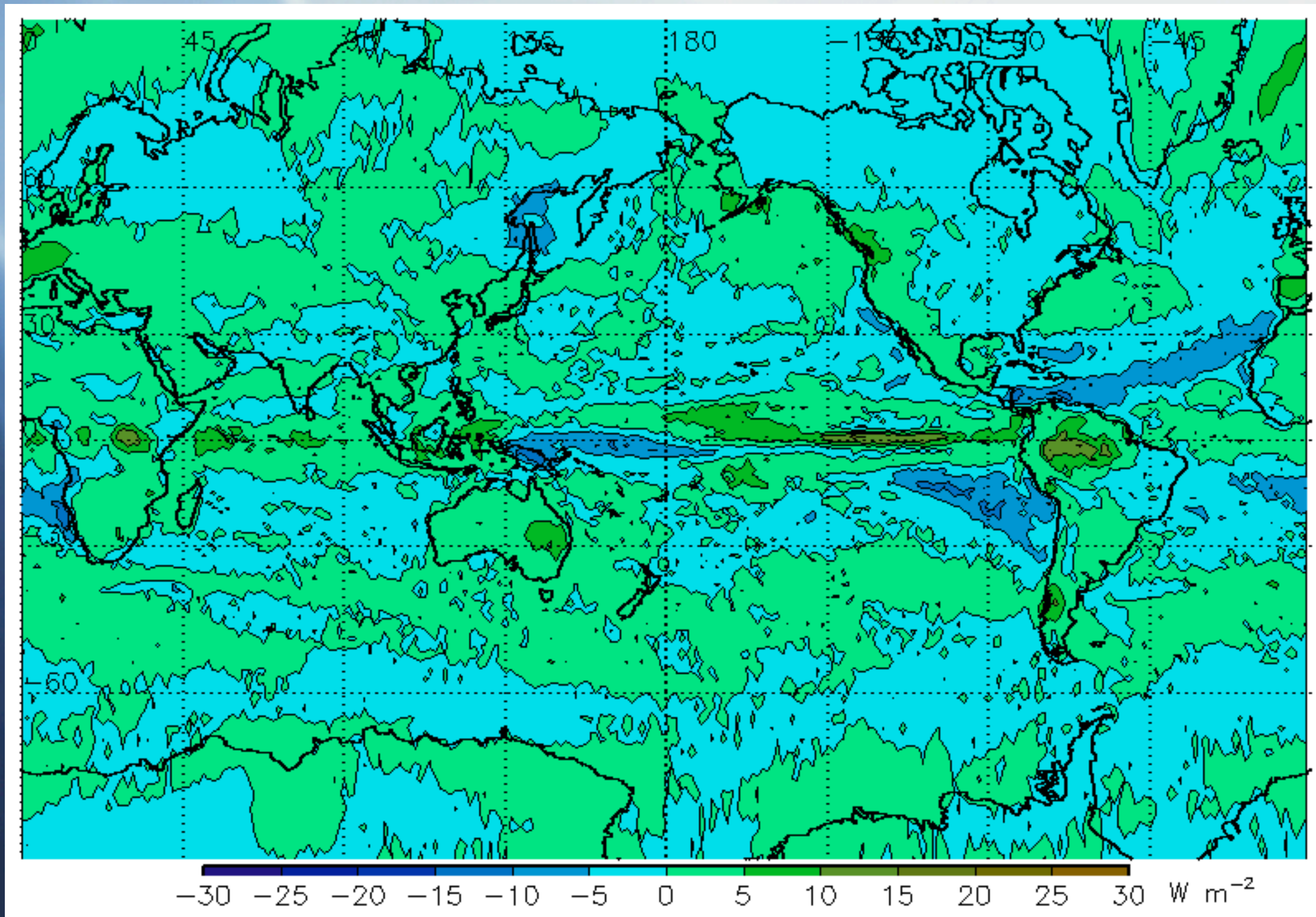
Research Question

- What is the seasonal distribution of the radiative contributions to global,annual mean feedbacks?

ΔCRF-adjusted



Net Cloud Radiative Forcing



Seasonal Variations
Temperature, LW